Simulation of asymmetric shot start in small caliber ammunition

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Outline

ARL

1. Motivation - Short Barrel Experiment Observation
2. Small Caliber Accuracy
3. Jump Test
4. Asymmetric Engraving and Lateral Throwoff
5. Finite Element Model
6. Model Results
7. Conclusions

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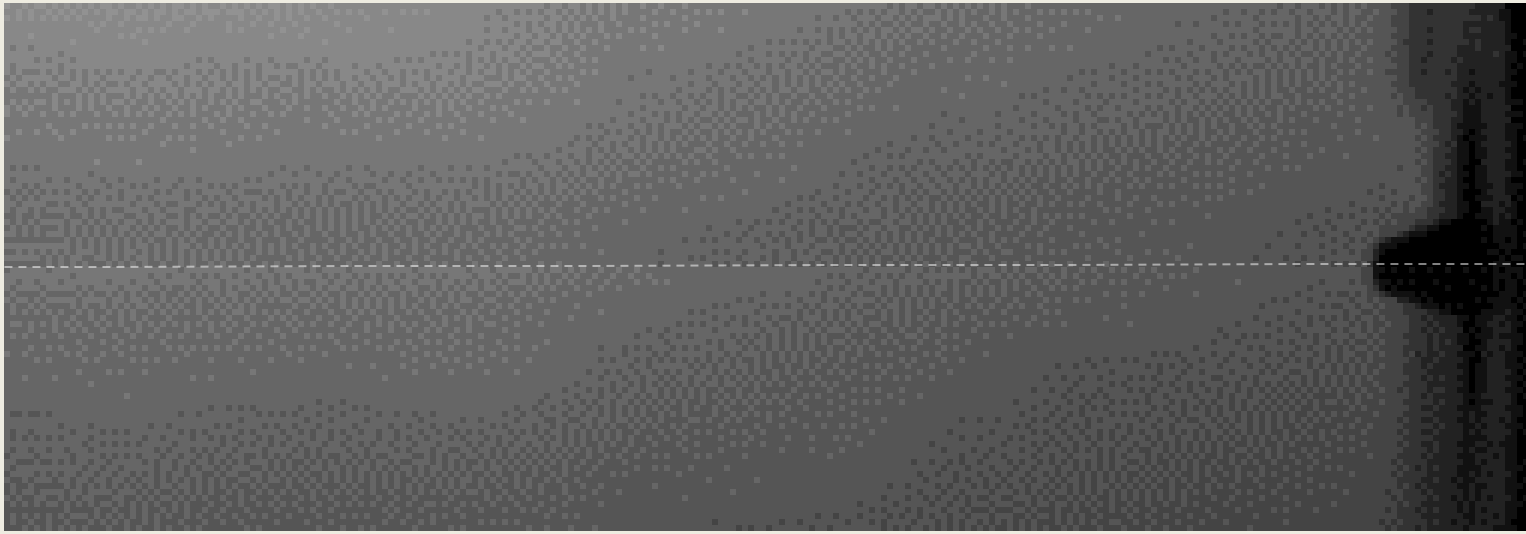
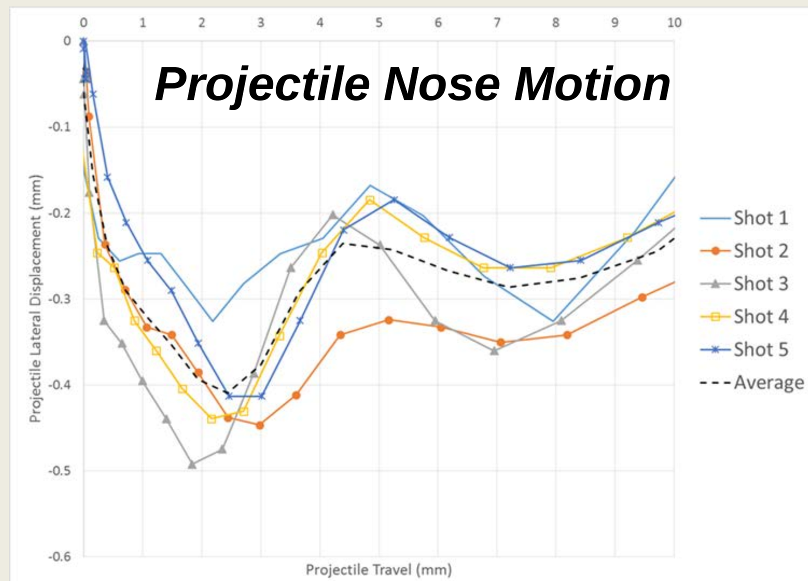
Short Barrel Experiments





Short barrel experiments have shown

- Primer ignition is sufficient to de-bullet projectile and begin engraving process
- As the projectile leaves the cartridge case its initial lateral motion is downward implying an upward motion of the projectile base.

Can this initial projectile motion affect projectile accuracy?

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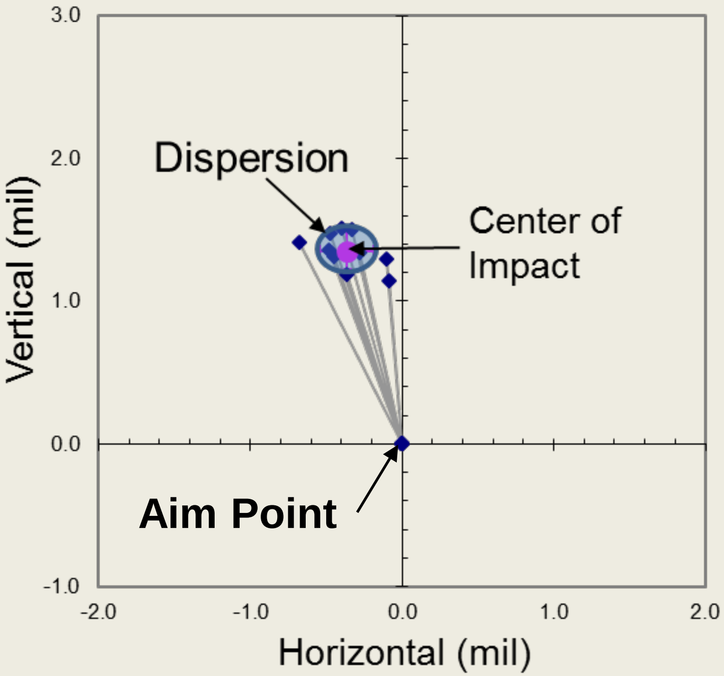
Small Caliber Accuracy



Center of Impact is the vector from the aim point to the experimental mean impact

Dispersion is the mean variation from the set mean

Measured in “mils” in vertical and horizontal planes where 6400 mil = 2π radians and a 1 mil dispersion is approximately equal to a 1 m offset from the aiming axis at 1000 m

Small Caliber Dispersion

We always want to reduce dispersion

Where does dispersion come from?

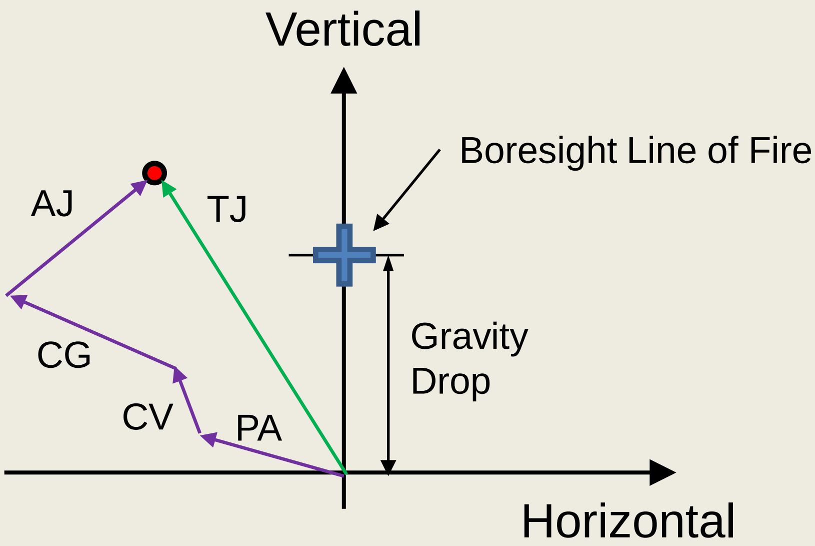
Complex interactions between the bullet, barrel, and flight conditions

Barrel characteristics	Projectile characteristics	Propulsion
Length	Mass asymmetries	Ullage
Barrel Mass / Stiffness	Assembly misalignment	Asymmetric Ignition
Wear and erosion	Materials	Charge
Centerline	Geometry & Tolerances	

How do we measure the significance of the various sources of dispersion?

We use the Jump Test – The Jump Test is a highly instrumented experiment that measures barrel dynamic motion and projectile position and orientation at multiple locations downrange in order to fit the pitch-yaw motion to the initial state at muzzle exit

Jump Test



Jump Components

TJ = Total Jump

PA = Muzzle Pointing Angle

CV = Muzzle Crossing Velocity

CG = CG Jump at Muzzle

AJ = Aerodynamic Jump

$$\overrightarrow{TJ} = \overrightarrow{PA} + \overrightarrow{CV} + \overrightarrow{CG} + \overrightarrow{AJ}$$

Sources of dispersion are assigned to different jump components

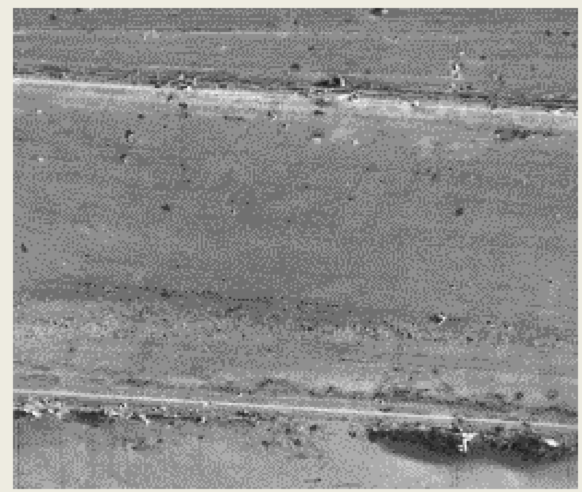
Some sources are grouped into single jump component

Asymmetric projectile motion at shot start will contribute to CG jump

- **Asymmetric Engraving**
- **Lateral Throwoff**

Asymmetric Engraving

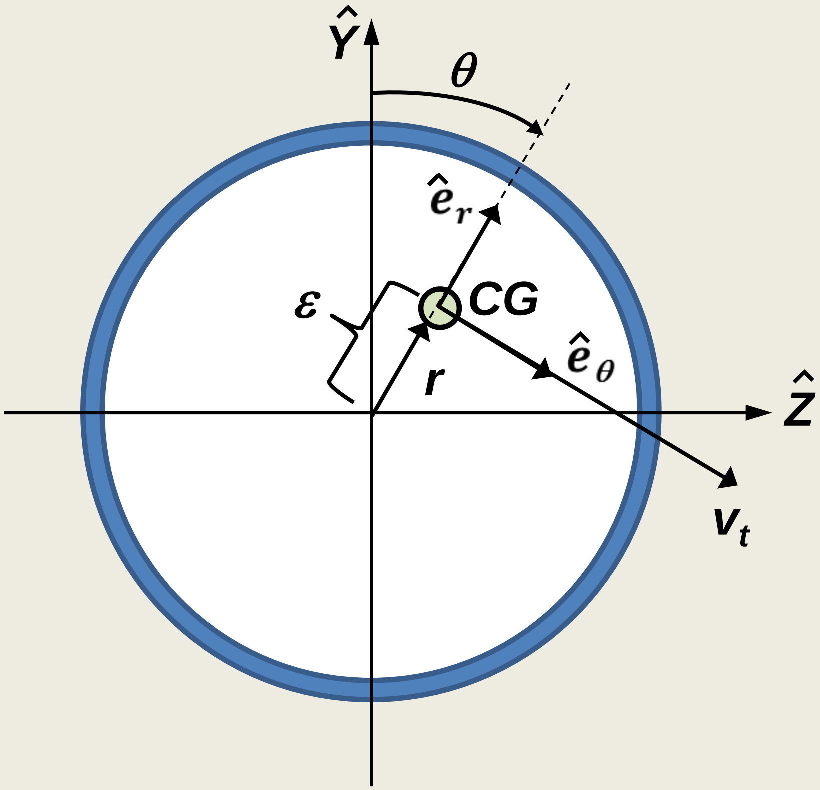
We have observed asymmetric engraving



asymmetric engraving can lead to mass asymmetry

Lateral Throwoff

(Relative) CG Jump consists of
- Barrel Centerline
- Projectile In-Bore Balloting
- Lateral Throwoff
- Muzzle Blast Effects



Lateral Throwoff

$$T_L = i\left[\frac{2\pi}{n}\frac{\vec{\varepsilon}}{d}\right]e^{i\theta_m}$$

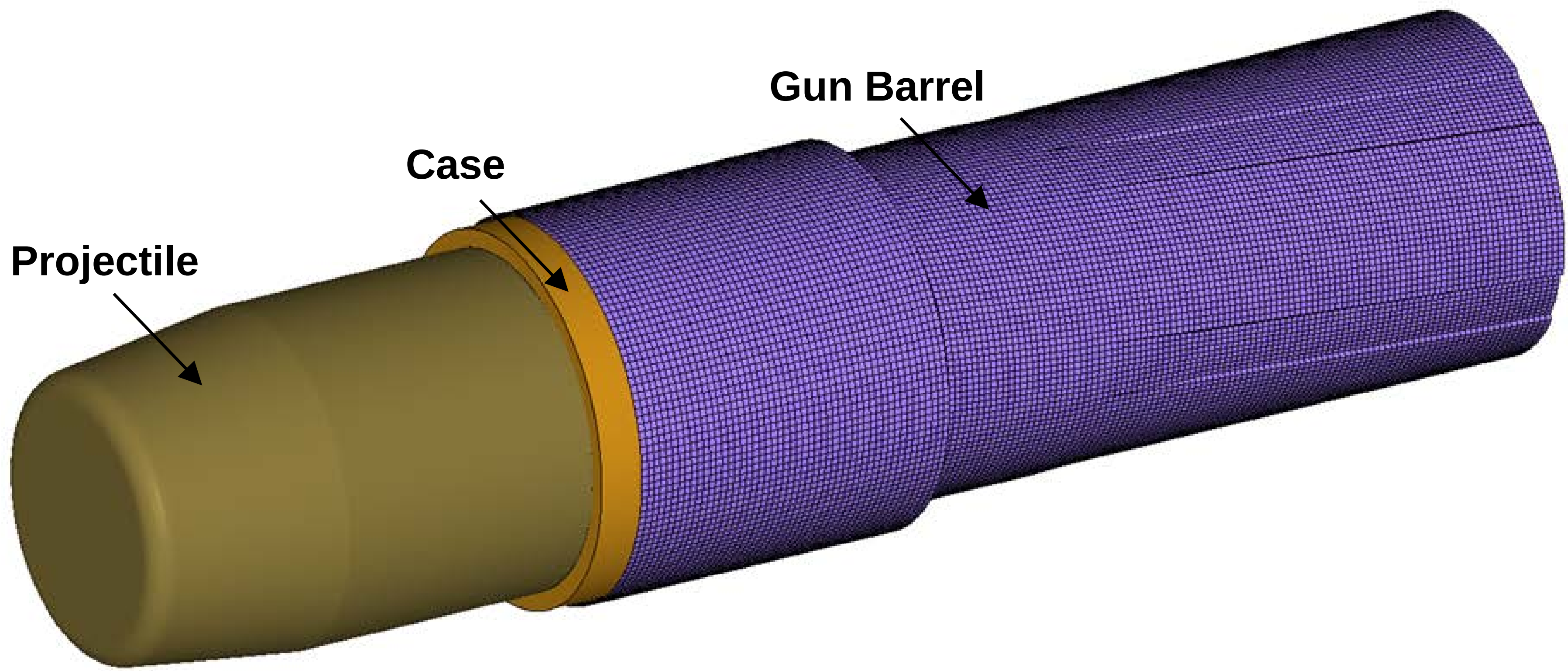
ε = CG lateral offset
n = rifling twist
d = projectile diameter
θ_m= roll orientation at muzzle

Effect of mass imbalance is to deflect trajectory in direction of CG tangent velocity at muzzle exit

Significant CG offset can affect aerodynamic jump $\overrightarrow{AJ}$ due rotation of principal moment of inertia axes

Finite Element Model

Simulate the early motion observed in the short barrel experiments to determine if the projectile develops any asymmetries which will increase dispersion by increasing the CG Jump

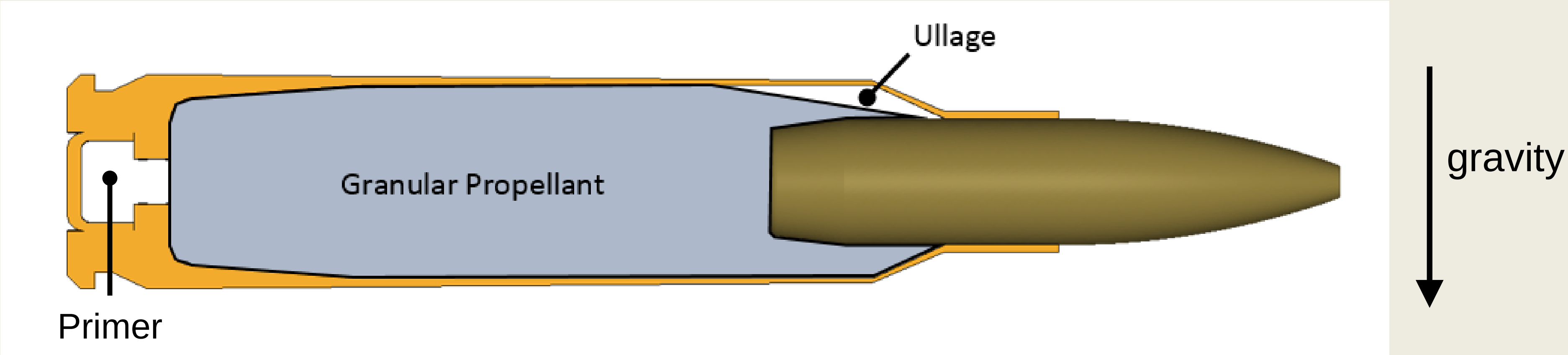


Projectile is created so that CG is along geometric centerline
Barrel is straight and rigid

Asymmetric Motion Source

Observation

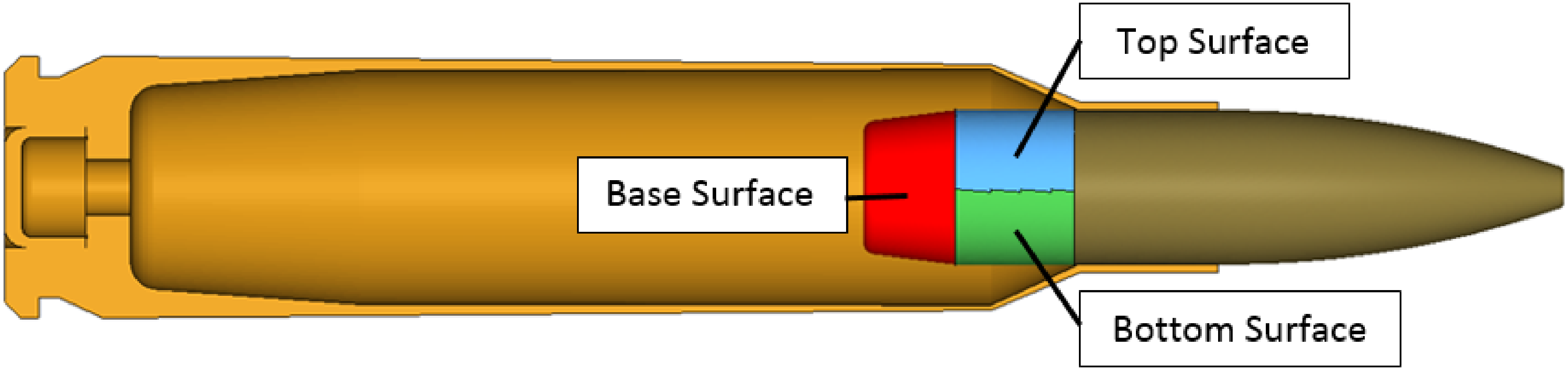
Projectile nose displaces downward at shot start implying an upward motion of the projectile base

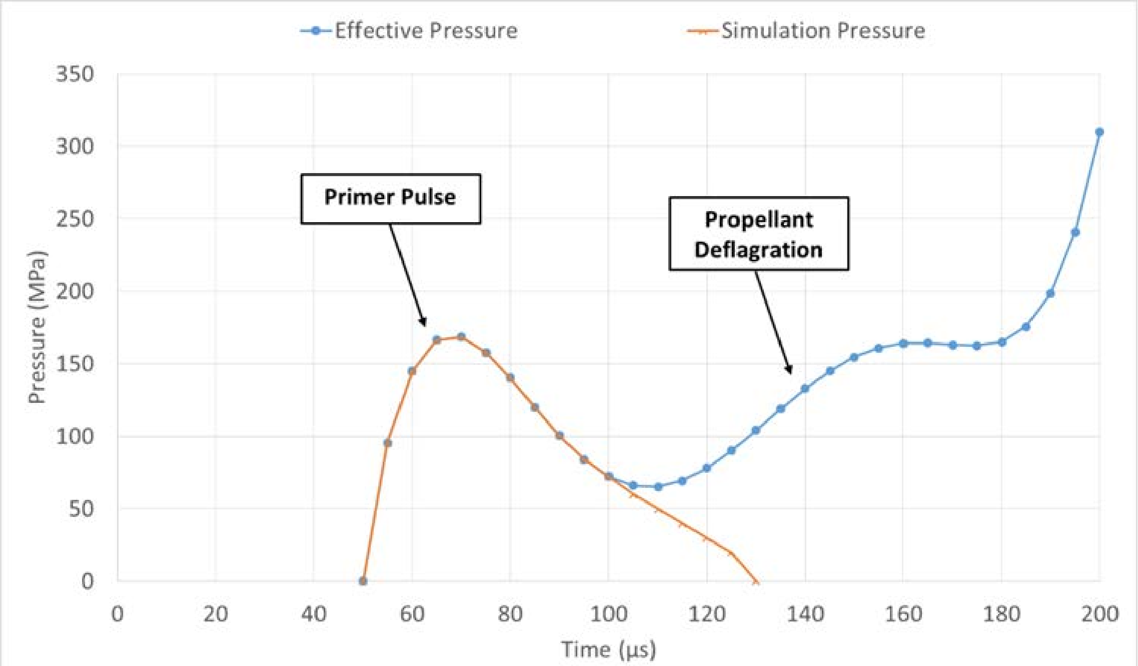


Hypothesis

Ullage located above the projectile boattail results in asymmetric loading of the projectile by the granular propellant bed during primer ignition

Asymmetric Motion Generation





Base pressure history predicted by IBHVG2 applied to *Base Surface*

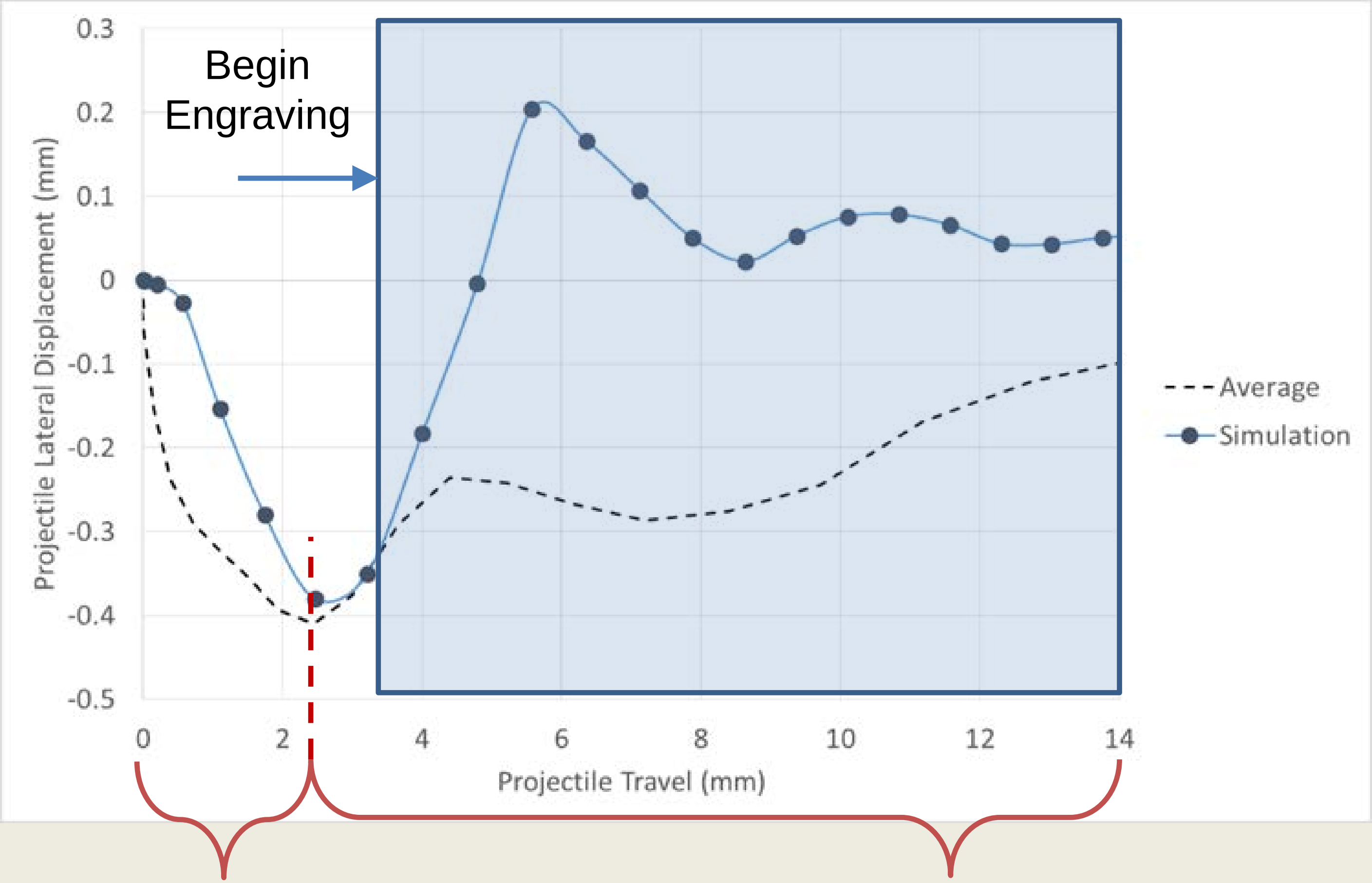
Lateral pressure estimated using primer force gage history and assumption of hydrostatic pressure in granular propellant bed

Lateral projectile motion generated by scaling the magnitude of top surface relative to bottom surface

$$P_{ratio} = 0.6 = \frac{Pressure\ (top\ surface)}{Pressure\ (bottom\ surface)}$$

FE Results

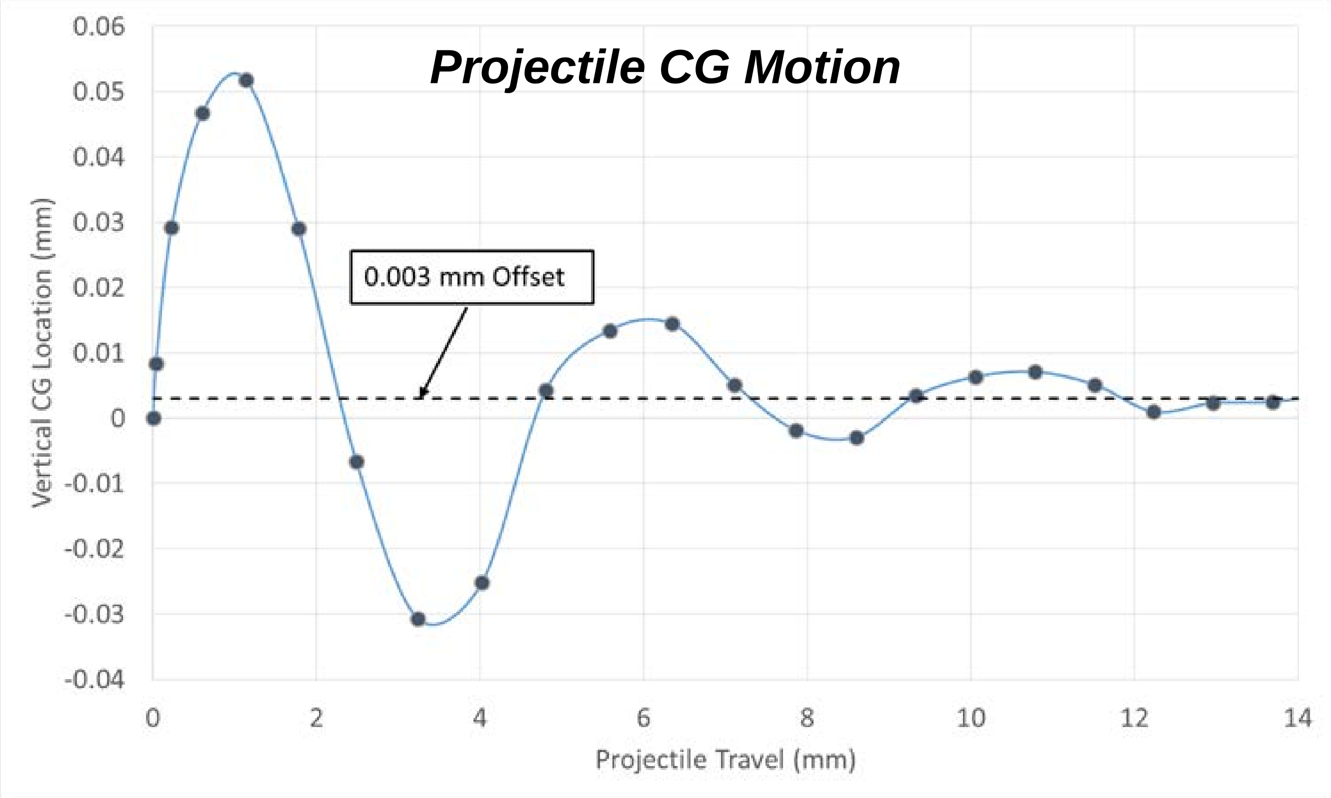
Projectile Nose Motion



Model compares well to average experimental data at first peak lateral displacement

Model results diverge from experimental data past first peak. Possible stabilizing effect of compressed propellant bed (not modeled)

CG Jump



Lateral Throwoff

$$T_L = i\left[\frac{2\pi}{n}\frac{\vec{\varepsilon}}{d}\right]e^{i\theta_m}$$

Projectile lateral CG history shows that asymmetric motion induces a small offset

Lateral throwoff magnitude $||T_L||$ ~ 0.1 mil for typical 5.56-mm weapon system

Small caliber ammunition exhibit total dispersion of ~ 0.3 mil

Summary

Asymmetric projectile motion at shot start has potential to induce moderate lateral throwoff that will result in increased dispersion

Source of asymmetric projectile motion is unclear – more testing is in-progress

Real projectiles have inherent CG offset due to manufacturing

The orientation of the as-manufactured CG offset at shot start is random, therefore the induced CG offset due to asymmetric engraving may increase or decrease the total CG offset

Backup Slides

Projectile Nose Motion